

The Role of Impact Gardening in Disturbing the Oxidation Stratigraphy of the Martian Regolith, A. P. Zent, SETI Institute and NASA Ames Research Center, Moffett Field CA 94035

Using new estimates of H₂O adsorption as the likely upper limit of peroxide adsorption, we estimate the upper limit of the depth of the oxidized layer of the martian regolith to be about 18 m. We then estimate the frequency of regolith turnover due to impact as a function of regolith depth. It is likely that the upper 10 m of regolith has been cycled through the oxidizing zone between 1 and 30 times in 3.6 Ga. Below about 200 m, the probability is that the regolith materials have never been mixed into the oxidizing zone. The probability of successful recovery of organics increases with depth.

The martian soil is strongly suspected to host several oxidizing species, which are invoked to explain the absence of organics in the martian soil and the curious release of O₂ on humidification of the martian soil. While a wide variety of mechanisms have been postulated, and the correct chemical mechanism is yet undetermined, many lines of evidence suggest that the process involves diffusion of one or more photochemically produced odd-H or odd-O species into the regolith, where they complexes with one or more surface sites on regolith minerals or mineraloids. First, photochemical models suggest that a variety of oxidizing species (H₂O₂, HO₂, O₃, OH, etc.) are produced in the martian atmosphere, and are present at the base of the atmosphere in the ppb range(1). Therefore, diffusion into the regolith is inescapable. Secondly, some models suggest that some kind of heterogeneous scrubbing processes must be invoked to throttle CO₂ recombination, and prevent elimination of atmospheric CO(2). Third, the number densities of oxidants derived from the Viking results are compatible with a surface phase(3).

The desire to acquire unoxidized species, which may be relict of the period when pre-biotic chemical evolution may have taken place on Mars, has led to discussions of drilling. The functional requirement for successful recovery of organics would be to penetrate the oxidized layer. As part of planning discussions for martian drilling, concern has been expressed that impact gardening would have stirred the stratigraphy of the regolith such that virtually all of the regolith materials would have moved repeatedly through the oxidizing zone(4). If this is the case, there is no reasonable probability of organic recovery, and drilling is not indicated. The objective of this report is to assess the probability of penetrating the oxidized surface layer as a function of drilling depth. We introduce new estimates of the oxidizing layer based on a model of peroxide diffusion into the regolith, and estimate the frequency with which materials from different depths would be overturned.

We proceed by assuming that H₂O₂ is the species responsible for the oxidative behavior of the martian regolith materials. This interpretation is consistent with the thermal stability criteria derived for the Labeled Release

experiment, as well as with recent laboratory results (5). We then estimate the depth of the oxidizing layer by solving the diffusion equation through a porous, adsorbing medium, with a loss term. For the upper boundary condition, we assume 1x10⁹ cm⁻³ H₂O₂. We solve the equation for the isothermal case of T=215 K. The equation describing diffusion through the regolith is taken as

$$\frac{d\sigma}{dt} = \frac{D_{eff}}{f + \frac{d\alpha}{d\gamma}} \left(\frac{\partial^2 \sigma}{\partial z^2} \right) - \lambda \sigma$$

where σ is the total concentration of H₂O₂, λ is its lifetime in the regolith, and the term $d\alpha/d\gamma$, the derivative of the adsorption isotherm with respect to the number density of the gas phase, represents scaling of the effective diffusion coefficient to account for adsorptive slowing. The loss term encompasses several mechanisms, including self-catalysis and reaction with Fe-oxides, and is not constrained experimentally. By assuming an adsorption isotherm, and a lifetime against reaction in the regolith, Bullock et al. (6) explored the possible ranges of the extinction depth of H₂O₂ diffusing through the regolith. They explored two cases, concluding that if the long lifetime derived by Chyba et al (7) applies (i.e. 10⁵ years), then the extinction depth is about 2.3 m. If however, the Viking surface concentrations of 30 nmoles cm⁻³ are assumed as the boundary condition, the extinction depth is only 1.5 cm.

Bullock et al. (6) were forced to use an isotherm that describes the adsorption of water because no adsorption isotherms were, nor are they now, available for H₂O₂ on Mars-analog materials. The adsorption of water is a reasonable approximation to peroxide adsorption because their dipole moments and sizes are similar. Recently however, new measurements of H₂O adsorption on Mars analog materials have been measured (8), and it is clear that the adsorption isotherms assumed by (6) overestimate the actual adsorbed load by more than an order of magnitude. The new isotherm form is less easily integrated than the earlier form, but it is still straightforward to estimate the extinction depth from the Bullock et al results (6), because

to first order Z_e scales as $\sqrt{D_{eff}t}$. In this case, the Z_e increases from the estimates of Bullock et al by approximately a factor of 8. Therefore, we conclude that the maximum likely depth of oxidation due to this mechanism (i.e. the Lifetime Case) is about 18 m, and that in the Concentration Case, the effective extinction depth is about 12 cm.

These numbers cannot be used to estimate the depth to which we must drill however, because the stratigraphy of the martian regolith is stirred by aeolian processes near the surface, and throughout by impacts. We examine now the

timescale and frequency with which regolith materials are mixed into the oxidizing zone, and back again, in order to assess the probability that material at depth Z has been mixed through the oxidizing zone.

Melosh (9) presents some equations for estimating the turnover frequency of the regolith from estimates of its age and the parameters that describe the crater population. We use his equation (10.3.10) to examine the turnover frequency of the martian regolith as a function of depth (d)

$$t_{\text{ovr}} = \frac{4(b-2)}{\pi b c_{\text{eq}}} \left(\frac{d}{h_{\text{eq}}} \right)^{(b-2)} t_{\text{surf}}$$

Terrains on Mars are of a variety of ages, and are represented by different size frequency curves. In this case, we take two crater populations. Population 1 is characterized by $b=-2.1$ and $D_{\text{eq}} = 1.5$ km. For the 2nd population, $b = -3.5$ and $D_{\text{eq}} = 2$ km.

We amend the application of this equation somewhat, because hypervelocity impact craters < 50 m are rare on Mars, due to aerodynamic breakup of incoming bolides. Therefore there is no gardening in approximately the top 10m of the regolith. This region is more actively overturned by aeolian processes. The depth and timescale of aeolian mixing are poorly known, so the applicability of this analysis to the upper 10m is limited.

We further assume that crater ejecta is distributed evenly over an area with twice the area of the initial crater, and that all materials within the oxidizing zone are oxidized on a timescale short comparable to the overturn time. We assume further that the surfaces in question are 3.6 billion years old.

In Case 1, where the oxidizing zone is 18m deep, we find that the probability is high that the upper 70m of the regolith are completely oxidized, because of repeated excavation and emplacement in thin, near surface ejecta blankets. Even at 130 m, the probability is that half of the materials have been oxidized.

If we assume that the oxidizing zone is only 12cm deep, corresponding to an effective lifetime of approximately 4 terrestrial years (see 6) then impact gardening has not

competed effectively with aeolian mixing. The key to predicting the depth of oxidation in that case is to understand aeolian mixing depths.

Finally, assuming the steeper slope of the crater size frequency distribution, we find that the upper 90 m are fully oxidized, that the 50% probability of oxidation occurs at about 115 m, and that below 200m, the probability of oxidation is about 10%. On a surface such as this moreover, perhaps 30 impacts have stirred the upper 10 m in the past 3.6 billion years, meaning that even an extinction depth as shallow as 12 cm can oxidize almost 10 m regolith.

If the lifetime of peroxide is less than roughly a decade, and if the surface is not inordinately rich in small craters (i.e. b closer to -2 than -3), then aeolian mixing should be the dominant mechanism in determining the oxidation stratigraphy of Mars. If the lifetime is on the order of 10^5 years, mixing by impacts requires access to depths greater than about 150 m to have significant hope of recovering reducing materials.

References

- (1)Hunten (1979). *J. Mol. Evol.*, **14**, 57.
- (2) Atreya and Gu, (1994) *J.G.R.* **99**, 13,133.
- (3) Zent and McKay, ., *Icarus* **108**, 146 .
- (4) Briggs, (1996) Wkshp. Deep Drilling on Mars
- (5)Quinn and Zent, (1996) Sub. to: *Origins of Life*
- (6) Bullock et al., (1994) *Icarus*, **107**, 142.
- (7) Chyba et al., (1989) *LPSC XX*, 157.
- (8) Zent and Quinn, (1997) *JGR*, In press
- (9) Melosh, (1989) *Impact Cratering*, Oxford

